A method and apparatus for mechanically grinding the end cutting teeth in a tool (such as a ball nose end mill) having spiral flutes and end cutting teeth that join with axial fluting. Rotary movement of an end cutting tool about a vertical axis is mechanically transmitted into corresponding rotary movement of the tool about its own axis to uniformly and precisely generate a helical grind from a starting point on the nose of the tool to a blend with a helical axial flute. When doing work on a ball nose end mill, the present invention produces a gash with a desired rake, for example, a positive rake, and by tilting the grinding wheel the same machine is then used for grinding both the primary and secondary relief of the end cutting teeth.

23 Claims, 4 Drawing Figures
METHOD AND APPARATUS FOR GRINDING END CUTTING TOOLS

BACKGROUND OF THE INVENTION

1. Field of the Invention
The present invention relates to end cutting tools and other tools where radii must be generated and in a preferred embodiment to a method and apparatus for mechanically grinding the gash and the primary and secondary relief in a ball nose end mill.

2. Description of the Prior Art
According to the known prior art the gash in a ball nose end mill was manually ground resulting in the gash having a negative rake and also resulting in non-uniformity from one tool to the next. The O.D. relief was ground using a finger that followed the manually ground rake, whereby any imperfections in the rake were carried over and produced in the O.D. relief.

SUMMARY OF THE PRESENT INVENTION
The grinding machine of the present invention comprises a rotary table mounted for rotation about a vertical axis, a work holder on the rotary table having means for mounting the workpiece for rotation about its own axis, and means for mechanically transmitting accurate movement of the rotary table into accurate movement of the workpiece about its own axis. As the workpiece is rotated about the vertical axis of the rotary table and is moved into contact with a properly oriented grinding wheel, the motion transmitting means causes rotation of the workpiece about its own axis, resulting in the generation of a helical grind from a starting point on the nose of a ball nose end mill to a blend with a helical axial flute (to produce the gash or radial flute).

The preferred motion transmitting means comprises a cam on the vertical shaft of the rotary table associated with a cam follower, and a cable connected between the cam follower and a rack and pinion on the work holder, the pinion driving a rotatable spindle holding the workpiece.

This apparatus produces a high degree of uniformity from one workpiece to the next while also providing the gash with a desired rake, for example, a positive rake. The grinding wheel head is mounted on a spindle and is rotated to a different orientation with respect to the workpiece and the same motion transmitting means are used in grinding both the primary and secondary relief on the nose of the end mill. In using the apparatus of the present invention, for grinding both the gash and the O.D. relief, a plurality of passes are made of the workpiece toward the grinding wheel, after each of which the operator advances the workpiece a small distance toward the grinding wheel.

A particular advantage of the mechanically cut gash of the present invention is that of uniformity from one tool to the next, whereby the lifetime of each tool is known as compared to a manually ground tool, the lifetime of which varies considerably from one to the next. This result provides the advantage that there is much less down time in a numerically controlled machine using a ball nose end mill produced according to the present invention, because the end mill can be replaced at a known predetermined time and there is no lost down time due to periodic checking of the end mill to determine if it is still effective. As will be understood by one skilled in the art, the advantages of the gash of the present invention with a positive rake, relate to the proper formation of the chip and to better metal removal than is obtained with the prior art manually cut gash having a negative rake. A still further advantage of the mechanically produced ball nose end mill of the present invention is that it has an increased lifetime.

The mechanically ground O.D. relief of the present invention is much more accurate than was the O.D. relief of the prior art because the prior art used a finger that followed a manually ground rake; thus in the prior art all of the imperfections of the rake were carried over to the O.D. relief. The present invention also has the advantage of reducing the time involved in accomplishing both jobs of grinding the gash and the O.D. relief because both jobs can be done on the same machine.

BRIEF DESCRIPTION OF THE DRAWINGS
The present invention will be more fully understood by reference to the following detailed description thereof, when read in conjunction with the attached drawings, wherein like reference numerals refer to like elements and wherein:

FIG. 1 is a perspective view of the grinding machine of the present invention with the parts oriented for grinding the gash.

FIG. 2 is a partial front view of the machine of FIG. 1 with the parts oriented for grinding the O.D. relief, and also showing the cam-cam follower and a schematic diagram of the electrical and air pressure system;

FIG. 3 is a top plan view of the rack and pinion assembly; and

FIG. 4 is a front view of the rack and pinion assembly.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With detailed reference now to the drawings, FIG. 1 shows a grinding and gashing machine 2 of the present invention for holding, moving, and controlling the motion of a workpiece 4 (in this preferred embodiment, a ball nose end mill) with respect to a grinding wheel 6 for doing work upon the workpiece 4. The grinding and gashing machine 2 of the present invention comprises a workpiece support system 12 and a grinding wheel support system 14, both of which systems 12 and 14 are supported on a base 16.

The workpiece supporting system 12 comprises a base slide 18 mounted on a main table 19, main table 19 mounts on the base 16, a rotary table 20 mounted on the base slide 18, an upper slide system 22 mounted on the rotary table 20, and a work holder 24 mounted on the upper slide system 22. The base slide 18 is mounted for sliding movement in the directions shown by the arrow 26; the slide 18 can be moved by manually rotating a knob 27 or by fast traverse using lead screw bypass knob (not shown). The upper slide system 22 comprises a first slide 28 mounted on the rotary table 20 for sliding movement in the directions of the arrow 30, and a second slide 32 mounted on the first slide 28 for sliding movement in the directions of the arrow 34. The slides 28 and 32 can be moved by means of rotatable knobs 29 and 33, respectively. The slides 18, 28, and 32 are preferably ball bushing slides, the construc-
tion and operation of which are well known to those skilled in the art and such need not be described in further detail herein. The work holder 24 comprises a yoke 40, and a housing 42 tiltably mounted in the yoke 40. The housing 42 can preferably be tilted (and then locked in position) at any angle between about ±20° to the horizontal. The base slide 18, the rotary table 20, the upper slide system 22 and the work holder 24, provide many degrees of freedom in positioning the workpiece 4 with respect to the grinding wheel 6.

The grinding wheel support system 14 comprises a main horizontal slide 50, a vertical slide 52, and a rotateable wheel head assembly 54 for tilting the wheel head about a horizontal axis, to accommodate various helices which are standard in the art. For example, the wheel head assembly 54 preferably forms an angle of approximately 12 degrees to the vertical (in a counterclockwise direction from the vertical as viewed in FIG. 1).

Reference will now be made in detail in FIGS. 2-4 showing the apparatus of the present invention for mechanically transmitting motion of the rotary table 20 to motion of the workpiece 4 about its own axis. With reference to FIG. 2, the rotary table 20 is connected to a vertical shaft (diagrammatically shown by a dashed line 69 in FIG. 2), to which shaft 60 is connected a cam 62. Associated with the cam 62 is a cam follower in the form of a wheel 64 rotatably mounted on a rod 66. The rod 66 is positioned against a flexible cable 68 positioned inside of a cable housing 70. The cable housing 70 is fixedly secured to a bracket 72 connected to the base 16 of the machine 2. The rod 66 is slidably mounted with respect to the bracket 72.

The other end of the cable 68 is connected to a rack and pinion assembly 76. The housing 42 of the work holder 24 includes means (not shown) for rotatably mounting a chuck assembly 78 for rotatably holding the workpiece 4. A pinion 80 of the rack and pinion assembly 76 is connected to the chuck assembly 78 for causing rotation of the workpiece 4.

The rack and pinion assembly 76 more fully shown in FIGS. 3 and 4, comprises a mounting bracket 82 rigidly connected to the housing 42. The cable housing 70 is rigidly attached to the bracket 82, while the cable is positioned against a rod 84 slidably mounted in a bushing 86. The cable is connected to a rack 88 (in meshing engagement with the pinion 80) through an adjustment screw 90 and a plate 92.

In addition to the cable 68 being connected to the rack 88, an air pressure biasing system 94 (FIG. 2) is also connected to the rack 88 for biasing the cam follower wheel 64 against the cam 62 during the return stroke of each pass or grind. The air pressure biasing system 94 comprises a double acting air cylinder 96 having a piston (not shown), a piston rod 97, two apertures 98 and 99 in the cylinder 96, an air hose 100 connected to the aperture 99, an air source 102, and a solenoid actuated valve 104 in the air hose 100. The valve 104 is part of an electric circuit comprising a voltage source 106 and a microswitch 108 actuated by a handle 110. Air pressure on the order of 40 p.s.i. has been found to be completely satisfactory. The switch 108 is actuated to close the valve 104 when the handle 110 is pushed or moved in the direction causing clockwise (when viewed from above) rotation of the rotary table 20; the switch 108 opens by a spring bias on the handle 110 when the operator ceases to push on the handle, thus opening the valve 104. When the valve 104 is not actuated (i.e., when the operator is pulling on the handle 110 on the return stroke), air pressure is exerted on the piston (not shown) causing it to move to the left as viewed in FIGS. 3 and 4, thus causing a pushing force to the left as viewed in FIGS. 3 and 4 to be exerted against the cable 68 to force the cam follower wheel 64 against the cam 62 on the return stroke. On the grind stroke, when the rotary table 20 is moved clockwise, air pressure is not needed to force the cam follower wheel 64 against the cam 62 because during this direction of rotation the cam 62 is on the rise pushing against the wheel 64.

The orientation of the grinding wheel 6 and the workpiece 4 shown in FIG. 1 is used for grinding the gash in a ball nose end mill. An operator manually moves the workpiece 4 into contact with the grinding wheel 6, from a starting point on the nose of the end mill, by causing clockwise (as viewed from above) arcuate movement (of approximately 90°) of the rotary table 20. The operator moves the rotary table by pushing on the handle 110. As the grinding wheel goes deeper into the workpiece 4, the workpiece 4 is caused to rotate about its own axis (clockwise as viewed from the work holder 24) by the action of the cam 62 against the cam follower wheel 64 and the rack and pinion assembly 76. After each pass or grind, the operator then returns the rotary table to its original starting position by pulling it counter-clockwise; during this return movement the workpiece 4 is caused to rotate counter-clockwise by the action of the air pressure system 94 on the rack and pinion assembly 76. After the return to the original position, the operator advances the slide 32 a predetermined amount by rotating the knob 33. The operator continues this procedure until the grinding of the gash is completed. A flute indexing means comprising a knob 79 and an index plate 81 is provided for multiple flute end cutting tools.

The machine 2 is also used to grind the O.D. relief after the gash has been ground. In order to grind the O.D. relief, the wheel head assembly 54 is rotated clockwise (as viewed in FIG. 1) approximately 90° to the horizontal position shown in FIG. 2. The housing 42 is then tilted up so that the axis of the workpiece 4 is also horizontal, as shown in FIG. 2. The primary relief is cut first, then the grinding wheel 6 is lowered slightly by means of the vertical slide 52, and the secondary relief is cut. In both jobs of grinding the primary and the secondary reliefs in the ball nose of the workpiece 4, the same mechanism described above for transmitting arcuate movement about the vertical axis of the rotary table 20 to arcuate movement of the workpiece 4 about its own axis is used, while the operator manually oscillates the rotary table 20, first turning it in a clockwise direction, then in a counter-clockwise direction, and then advancing the workpiece toward the grinding wheel 6 a predetermined amount using the slide 28 and the knob 29. In this way the same machine can be used to machine control the grinding of both the gash and the O.D. relief.

The cam 62 preferably includes three separate lobes, each one corresponding to one of the standard helices for an end mill (i.e. low, medium and high). Alterna-
tively the cam 62 can have a single lobe and can be replaced with a different cam when grinding an end mill having a different helix. The combination of the main slide 50 and the base slide 18 provide for placing the periphery of the grinding wheel 6 in a predetermined position relative to the centerline of rotation of the rotary table 20. This makes possible an offset position of the workpiece 4 relative to the grinding wheel 6 so that the grind will be from a fade out depth at the nose to full flute depth along the axial flute. The apparatus and method of the present invention can be used on various types of tools having spiral flutes and end cutting teeth that join with axial fluting, such as ball nose end mills, drills, counter bores, counter sinks, reamers, and other special tools. Other means for transmitting arcuate movement about a vertical axis to arcuate movement of the tool about its own axis, including, for example, gearing, can be used in place of the particular preferred apparatus described hereinabove.

The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention as described hereinabove and as defined in the appended claims.

I claim:

1. In a grinding machine for grinding the gash in a workpiece having helical fluting and to be formed, by cutting the gash, into a tool having helical fluting and end cutting teeth formed by curvature radial fluting merging with said helical fluting, said machine including a grinding wheel and means for holding said workpiece, the improvement comprising:
   a. means for rotatably mounting the workpiece about a first axis approximately perpendicular to the axis of the workpiece for movement of the workpiece into contact with said grinding wheel;
   b. means for rotatably mounting the workpiece for rotation about its own axis,
   c. means for mechanically transmitting arcuate movement of said workpiece about said first axis into smooth, accurate, predetermined arcuate movement of said workpiece about its own axis, and
   d. means for positioning said workpiece relative to said grinding wheel for automatically grinding the gash in said workpiece when said rotary table is accurately moved, said gash curving from a fade out depth at a nose of said workpiece to a full flute depth blending with one of said helical flutes.

2. The apparatus according to claim 1 wherein said means for grinding the gash includes means for accurately rotating said grinding wheel about an axis perpendicular to the axis of rotation of said grinding wheel, said means for longitudinally moving said grinding wheel along the axis of rotation of said grinding wheel and means for tilting said workpiece in a vertical plane to plus or minus a predetermined number of degrees above and below horizontal.

3. The apparatus according to claim 2 wherein said workpiece is a ball nose end mill, and wherein said means for grinding the gash in said workpiece comprises means for generating a plurality of grinds for grinding the gash, each successive grind being deeper as it blends with a corresponding helical flute until full flute depth is reached.

4. The apparatus according to claim 3 including means for tiltably adjusting said grinding wheel to position its axis horizontal, means for tiltably adjusting said workpiece mounting means to position the axis of the workpiece horizontal, and means for vertically adjusting the position of the grinding wheel, whereby said machine can also grind the primary and secondary relief of the end cutting teeth of said ball nose end mill.

5. A grinding machine for grinding the gash in a workpiece having helical fluting and to be formed, by cutting the gash, into a tool having helical fluting and end cutting teeth formed by curvature, radial fluting merging with said helical fluting, comprising:
   a. a rotary table mounted for arcuate movement about a first axis;
   b. a work holder fixedly connected to said table for arcuate movement therewith;
   c. a workpiece holding assembly for holding a workpiece, said assembly being mounted on said work holder for arcuate movement about a second axis, said second axis being the axis of a workpiece held by said assembly;
   d. means for mechanically transmitting arcuate movement of rotary table about said first axis to a predetermined amount of arcuate movement of said workpiece holding assembly about said second axis,
   e. a grinding wheel mounted for rotation adjacent to said workpiece, and
   f. means for positioning said workpiece relative to said grinding wheel for automatically grinding the gash in said workpiece when said rotary table is accurately moved, said gash curving from a fade out depth at a nose of said workpiece to a full flute depth blending with one of said helical flutes.

6. The apparatus according to claim 5 wherein the axis of rotation of said grinding wheel is located in a vertical plane, and wherein said grinding wheel includes an assembly mounted for arcuate rotation about a horizontal axis, and also includes movable slide means movable longitudinally of the axis of rotation of said grinding wheel, for orienting the periphery of said grinding wheel in a predetermined position relative to said workpiece for grinding said gash.

7. The apparatus according to claim 6 wherein said work holder includes means tiltably mounting said chuck assembly for positioning said second axis anywhere within the range of from about 20° above to 20° below the horizontal.

8. The apparatus according to claim 7 wherein said workpiece is a ball nose end mill, wherein said first axis is approximately vertical, said second axis makes an angle of approximately 15 degrees below the horizontal, and said third axis is approximately vertical, and wherein said transmitting means includes a cam connected to a vertical shaft connected to and rotating with said rotary table, and a cam follower in contact with said cam and connected to said workpiece for translating arcuate motion of said cam to arcuate motion of said workpiece.

9. A grinding machine for doing work on a workpiece comprising:
   a. a rotary table mounted for arcuate movement about a first axis;
   b. a work holder fixedly connected to said table for arcuate movement therewith;
c. a workpiece holding assembly for holding a workpiece, said assembly being mounted on said workholder for arcuate movement about a second axis, said second axis being the axis of a workpiece held by said assembly;
d. means for mechanically transmitting arcuate movement of rotary table about said first axis to a predetermined amount of arcuate movement of said assembly about said second axis,
e. said rotary table including a shaft having said first axis as the axis of rotation of said shaft, said shaft being connected to said rotary table for rotation therewith, and wherein said transmitting means comprises:
f. a cam mounted on said shaft;
g. a cam follower positioned against said cam for following a rise and fall of said cam;
h. a rack and pinion assembly mounted on said workholder, said pinion being connected to said chuck assembly for rotation therewith and said rack being in meshing engagement with said pinion; and
i. a cable connected at one end to said cam follower and at the other end to said rack, whereby arcuate movement of said rotary table about said first axis is mechanically transmitted to said assembly causing a predetermined arcuate movement about said second axis of a workpiece held by said assembly.

10. The apparatus according to claim 9 including fluid control means for forcing said cam follower into contact with said cam.

11. The apparatus according to claim 10 wherein said fluid control means comprises an air pressure source, a cylinder piston assembly including a piston rod associated with said cable such that it can force said cam follower against said cam, an air line connected from said source to said cylinder, a solenoid valve biased to its open condition positioned in said air line, for controlling the application of air pressure to said cylinder, a microswitch for energizing said solenoid valve to its closed condition, a handle for opening and closing said microswitch, said handle being biased to maintain said microswitch open and being movable to close said microswitch only when said handle is used to rotate said rotary table during a forward (i.e., clockwise) stroke.

12. The apparatus according to claim 9 wherein said cam has three lobes corresponding to three standard helices used on ball nose end mills.

13. The method of grinding the gash in a workpiece having helical fluting and to be formed, by cutting the gash, into a tool having helical fluting and end cutting teeth formed by cutting radial fluting blending with said helical fluting, said method comprising:
a. moving said workpiece about a first axis, approximately perpendicular to the workpiece axis, into contact with a rotating grinding wheel,
b. simultaneously rotating said workpiece a predetermined amount about its own axis in accurate, predetermined response to arcuate movement of said workpiece about said first axis, and
c. grinding a uniform, smooth, curving, radial gash in said workpiece from a fade out depth at a nose of said workpiece to full flute depth where a radial flute blends with a corresponding helical flute.
23. The apparatus according to claim 8 wherein said grinding means includes means for grinding a gash with a positive rake.

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